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Effects of Water and Mineral Nutrient Deficiencies on Pyrrolizidine Alkaloid Content of *Senecio vulgaris* Flowers

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Abstract: The flowers of *Senecio vulgaris* contain the alkaloids senecionine, seneciphylline, and their N-oxides, compounds which are toxic to some grazing animals. Deficiencies of water, mineral nutrients, or both did not significantly alter concentrations of the individual alkaloids. However, more favourable growing conditions resulted in a greater quantity of flowers, which animals find quite palatable, so that each of these plants was potentially more toxic because it contained a larger total amount of the alkaloids.

Key words: pyrrolizidine alkaloids, *Senecio vulgaris*, range, weed, water, nutrient, toxicity.

INTRODUCTION

Grazing of rangeland plants that contain pyrrolizidine alkaloids can be hazardous to those animals that are sensitive to this class of compounds. However, the concentrations of alkaloids in the plants are not constant, but vary from season to season, from year to year, and from one location to another at the same time (Johnson *et al* 1985). The alkaloid content may also vary with the physiological age of the plants, since in certain species, toxicity appears to peak during flowering or seed production. Annual variations in alkaloid content suggest metabolic responses to climate, nutrients, or water supply, in addition to genetic variations between plants in different locations.

On arid rangelands, such as those in the western USA, the large area required to support an animal makes it impractical to use the chemical or cultural weed control methods that are appropriate for more intensely grown crop plants. Instead, appropriate range management may require controlling the animals' access to weed-infested areas at certain stages of the plant's growth. Because determination of the alkaloid content is a relatively complex laboratory procedure, it would be preferable to have a basis for predicting the probability of toxicity at any time as a function of plant growth and/or environmental factors.

Plants growing on rangelands are subjected to a large number of environmental variables, including annual and diurnal cycles of day length, light intensity, and temperature, changing air movement, humidity, and rainfall, and differences in soil structure, nutrients, and moisture retention. Furthermore, the consequences of a given set of these conditions may vary with the physiological age of the plant. For an initial understanding of the influences of these factors, it seemed appropriate to alter several, while keeping the remaining ones constant by growing the plants in a growth chamber.

Water and soil fertility, two of the factors suggested by Johnson *et al* (1985) as possibly influencing alkaloid synthesis, were selected as the initial experimental variables. *Senecio vulgaris* L, mentioned by the same authors as of significant economic impact but not analysed extensively by them, was selected as the subject of this work. Hartmann and Zimmer (1986) reported that most of the alkaloids in this plant were found in the flowers. Since the flowers are grazed, often in preference to the remainder of the plant, they seemed an appropriate experimental material. By picking them just prior to opening, a sufficient quantity of tissue of uniform physiological age could be accumulated for

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analysis. In contrast, leaves at different positions on the stem can have appreciably different metabolic levels and composition, even though they are analysed at the same time (Brown and Bethlenfalvay 1987).

EXPERIMENTAL

Seeds from a single *Senecio vulgaris* plant were germinated, and one plant was transplanted into each of 20 15 cm plastic pots of Yolo sandy loam soil, each containing a gypsum-block moisture sensor (Soilmoisture Eqpt Corp, Santa Barbara, CA, USA).

A factorial experiment consisting of two levels each of water and nutrients, with five replications (one plant each) of each treatment combination, was arranged in the growth chamber so that effects of position could be detected. During the first 8 weeks, all plants received water as needed. During the following 7 weeks, soil moisture was measured daily. Plants to be kept moist were watered before the soil suction fell to a level of 0·4 bar, but water was not added to the dry ones until the suction had reached at least 10 bars, at which slight wilting was observed. Once weekly, plants of the high-nutrient treatment received nutrient solution (N, P, K, Ca, Mg, Fe) instead of water.

Beginning the third week of controlled watering, flowers were picked just as they began to show a yellow colour. The flowers from each plant were collected daily and kept frozen until the end of the growth phase of the experiment, then dried, ground, and extracted according to the procedure described by Mattocks (1986). Alkaloids were measured by HPLC (Brown *et al* 1994). Data were analysed with SigmaStat two-way analysis of variance (Jandel Scientific 1992).

RESULTS AND DISCUSSION

As might be expected, the production of flowers was greatest when the plants were provided with both water and nutrients. Of the single deficiency treatments, absence of additional nutrients was more detrimental than lack of water. With the schedule of watering and feeding employed in this experiment, withholding both water and nutrients was no more detrimental to flowering than withholding nutrients alone (Table 1). Apparently the plants were able to benefit from adequate watering only where nutrients were not limiting.

Senecionine (SE) and seneciphylline (SP), present as both the free bases and the N-oxides (NO), comprised 85–90% of the alkaloids of the young flowers. The concentrations of the NO were approximately three (SE) to four (SP) times the concentrations of the free bases. Contrary to earlier assumptions (Johnson *et al* 1985), water and nutrient stresses did not significantly alter the concentrations of the alkaloids in these plants. There were, however, changes in the amounts of alkaloids that would be available to grazing animals. These were the result of decreases in flower production in response to water and nutrient deficiencies. Lack of adequate water and nutrients made a statistically significant, but nevertheless small decrease in the amounts of the lesser components, the free bases, of the major alkaloids in the flowers from each plant. Interestingly, neither deficiency alone significantly reduced the concentrations or amounts of the individual alkaloids, even though each did decrease flower production.

The totals of these four alkaloids, however, was decreased by an average of 50% by water and/or nutrient deficiencies. This apparent contradiction to the above statements of the individual alkaloids appears to be a consequence of the variability of individual alkaloid components between plants (Van Borstel *et al* 1989), whereas the totals were more consistent.

Viewed from the range management standpoint, for those animals to which the free base and NO forms of pyrrolizidine alkaloids are toxic, favourable growing conditions significantly increased the toxicity, ie the total alkaloid content, of *S vulgaris* plants over those plants growing under either or both of the deficiency regimes.

TABLE 1

Weight of flowers, and concentrations and weights of senecionine (SE), seneciphylline (SP), and their N-oxides (NO) from *Senecio vulgaris* plants grown with two levels of water and nutrients[a]

Growth conditions	*Flowers*[b] *(g)*	*Alkaloid concentration (mg g*$^{-1}$*)*[c]				*Alkaloid amount (mg)*				
		SE	*SE NO*	*SP*	*SP NO*	*SE*	*SE NO*	*SP*	*SP NO*	*Total*
Moist, nutrient	1·32a	0·43	1·75	0·10	0·79	0·60ab	2·17	0·14ab	0·99	3·90a
Moist, water	0·75c	0·62	1·44	0·20	0·53	0·49ab	1·08	0·15ab	0·38	2·10b
Dry, nutrient	1·14b	0·92	1·24	0·19	0·40	1·02a	1·45	0·21a	0·48	3·16b
Dry, water	0·75c	0·49	1·94	0·12	0·58	0·30b	1·58	0·08b	0·46	2·42b

[a] In any column, values with the same following letter or none are not significantly different at $P = 0·05$.
[b] Dry weight of flowers per plant.
[c] mg alkaloid per g flowers.

Comparison of the leaf colour and size of these plants in the growth chamber with the parent plants outdoors suggests that none of these treatments supplied the level of nutrients that was available to plants growing as weeds in the landscaped site from which seeds were originally collected. They may, however, be similar to conditions in some areas of range, which is unfertilized and may receive little rainfall during the flowering season.

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